



A THERMOELECTRIC COOLER CONTROLLER FOR THE NOVA APD BOXES

(PROGRESS REPORT)

G. VISSER

INDIANA UNIVERSITY CYCLOTRON FACILITY

5/9/2006

AT

NOVA ELECTRONICS/DAQ WORKSHOP, FERMILAB

Requirements for TEC Controller – *comments please!*

- Minimum cost, low component count, integrated on FEB
- Low noise (for a specific criterion, let's require that APD signal noise level seen through ASIC is not increased more than 1% when TEC controller is enabled)
- Efficiency as high as reasonable (looks like 80%, including cable losses)
- Input supply voltage chosen for system efficiency – we'll use 24VDC
- Isolation (at DC) from FEB ground
- **Fixed** $\approx -15\text{ }^{\circ}\text{C}$ setpoint, set by a fixed resistor value or trimpot, not linearized – *of course, remote control is possible, if we need it... #*
- TEC drive power: $\leq 5\text{ W}$ ($\leq 3\text{ W ?}$) #
- TEC I-V curve: Defined as TE-31-1.0-1.3, at $\Delta T=30\text{ K}$ (but I'm assuming $\Delta T=35\text{ K}$, a little more conservative)
- Temperature sensor: NTC thermistor, resistance $\approx 10\text{ k}\Omega$ at setpoint
- Remote readout of TEC drive level (or, at least, a status bit that loop is in regulation)
- Remote enable/disable (for in-system noise diagnostics, etc.)
- Remote readout of temperature? *Doesn't seem necessary, but...? #*
- Required temperature stability to $\pm 0.5\text{ }^{\circ}\text{C}^{\dagger}$ over aging, line variation, environmental $\pm 10\text{ }^{\circ}\text{C}$ (?)
- Absolute accuracy of setpoint $\pm 1\text{ }^{\circ}\text{C}^{\dagger}$ – *this could get expensive, I suggest $\pm 2\text{ }^{\circ}\text{C}$... #*

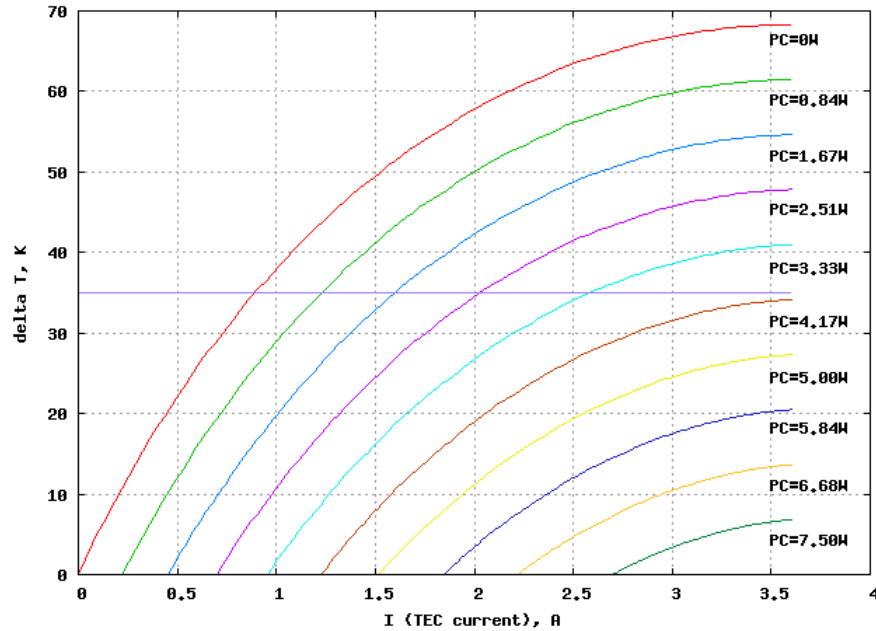
Notes:

\dagger From NOVA-doc-147-v4 – based on what considerations???

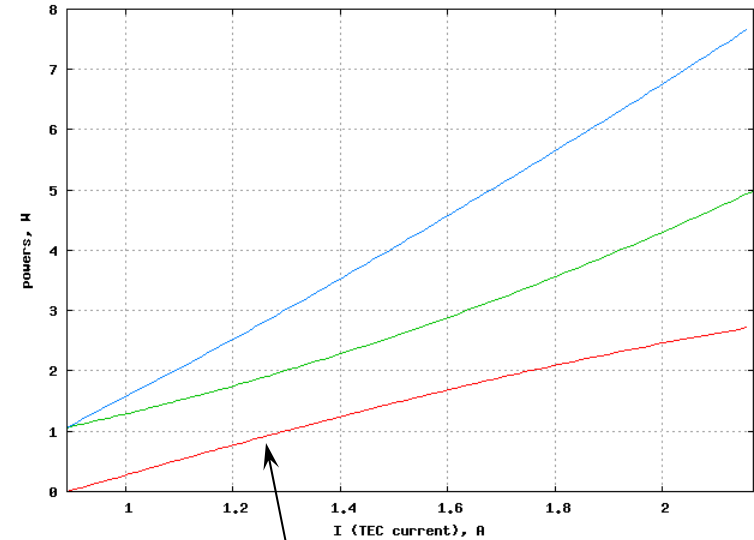
See slide 11 about resolution of these formerly open issues

TE-31-1.0-1.3 characteristics

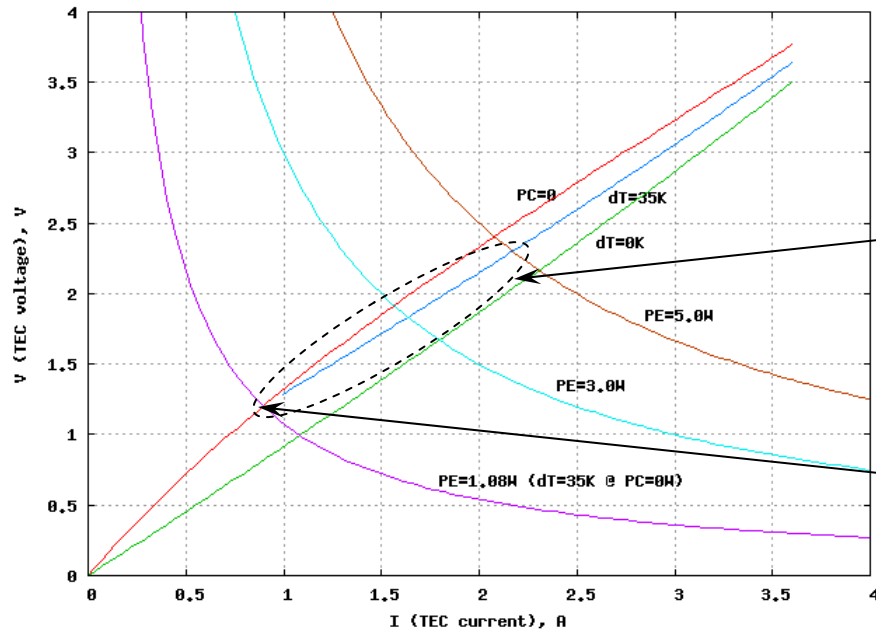
TE-31-1.0-1.3, delta T vs. I and PC



TE-31-1.0-1.3, cold, hot, and electrical power vs. I



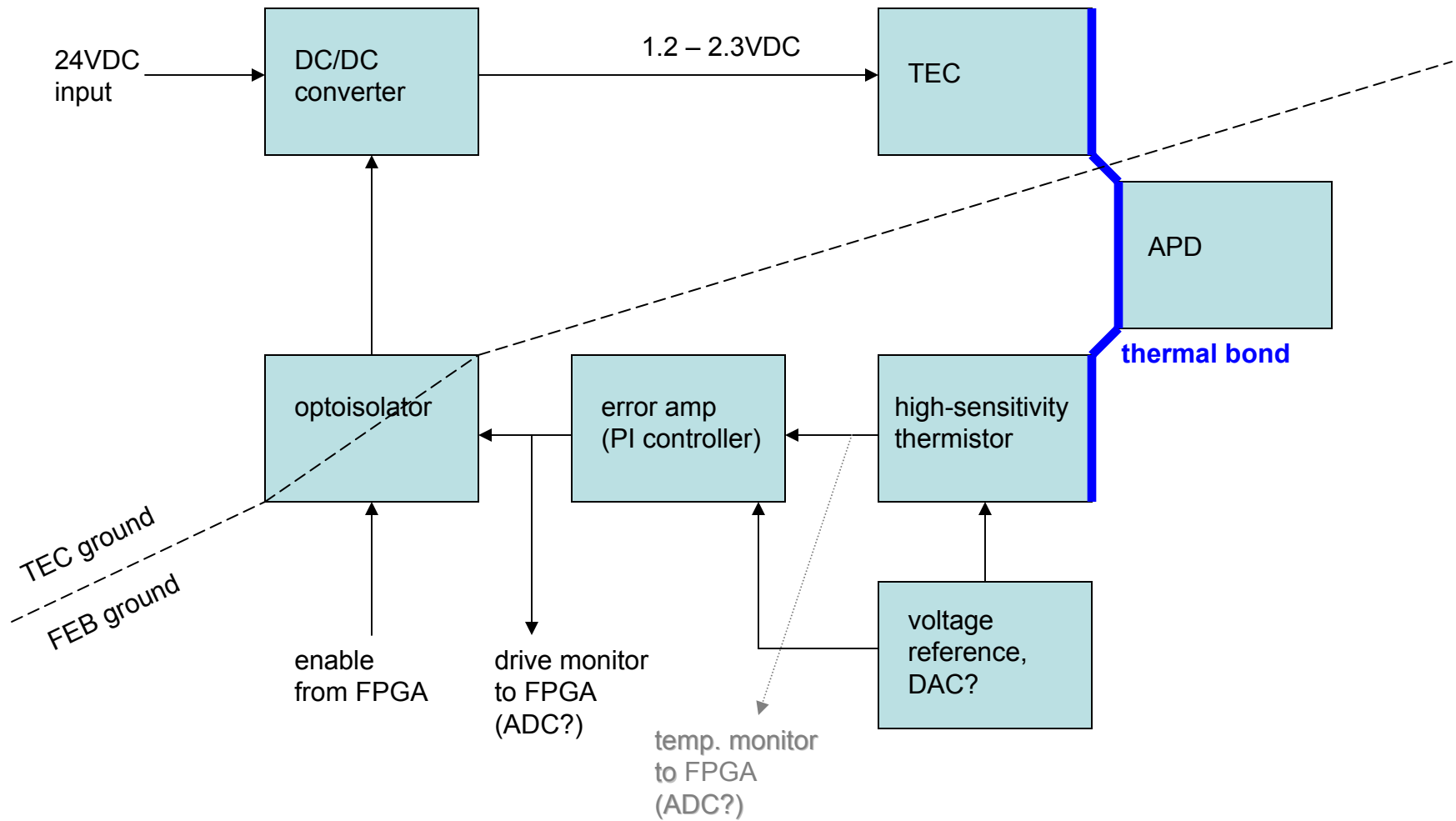
TE-31-1.0-1.3, V vs. I @ PC=0W, dT=35K, dT=0K



$V = 0.423 + 0.863 I$ is a good approximation, for $P_E < 5W$ ($I < 2.17 A$) and $\Delta T = 35 K$

Minimum 1.08 W to achieve $\Delta T = 35 K$

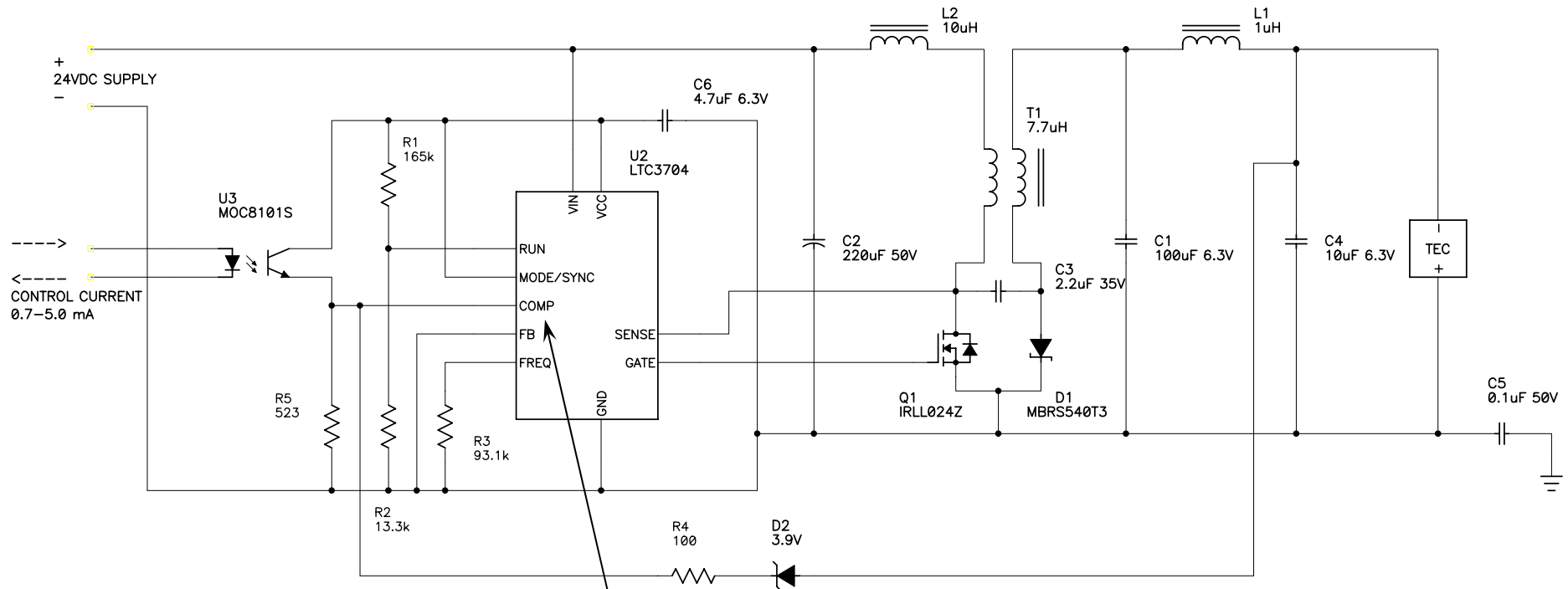
TEC Controller Block Diagram



TEC Controller DC/DC Converter

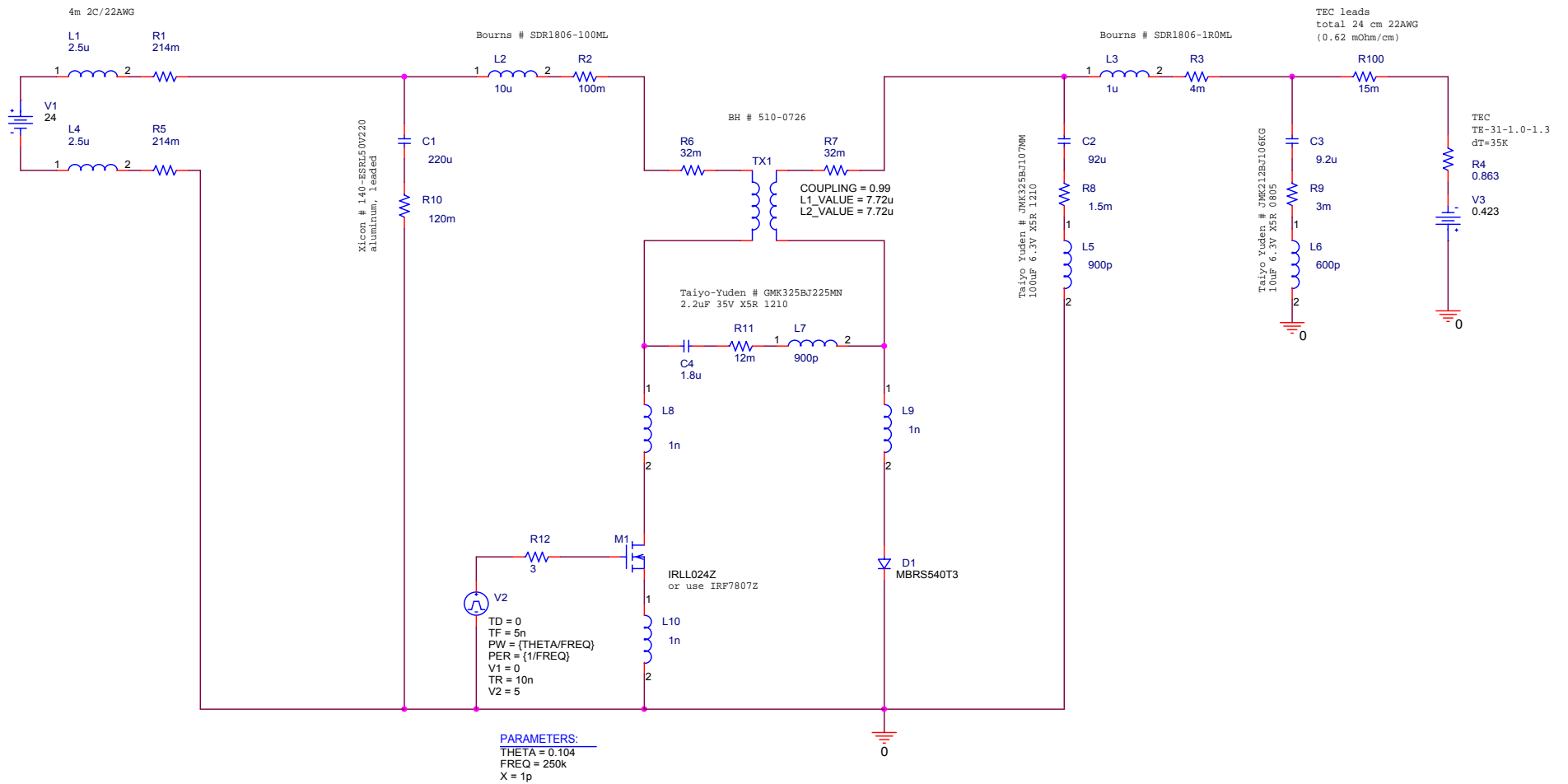
A 24V to 1 – 2.5V, “zero” input ripple, current-mode controlled Ćuk converter, with output filter

Component costs \approx \$7.00 @ 1k quantity

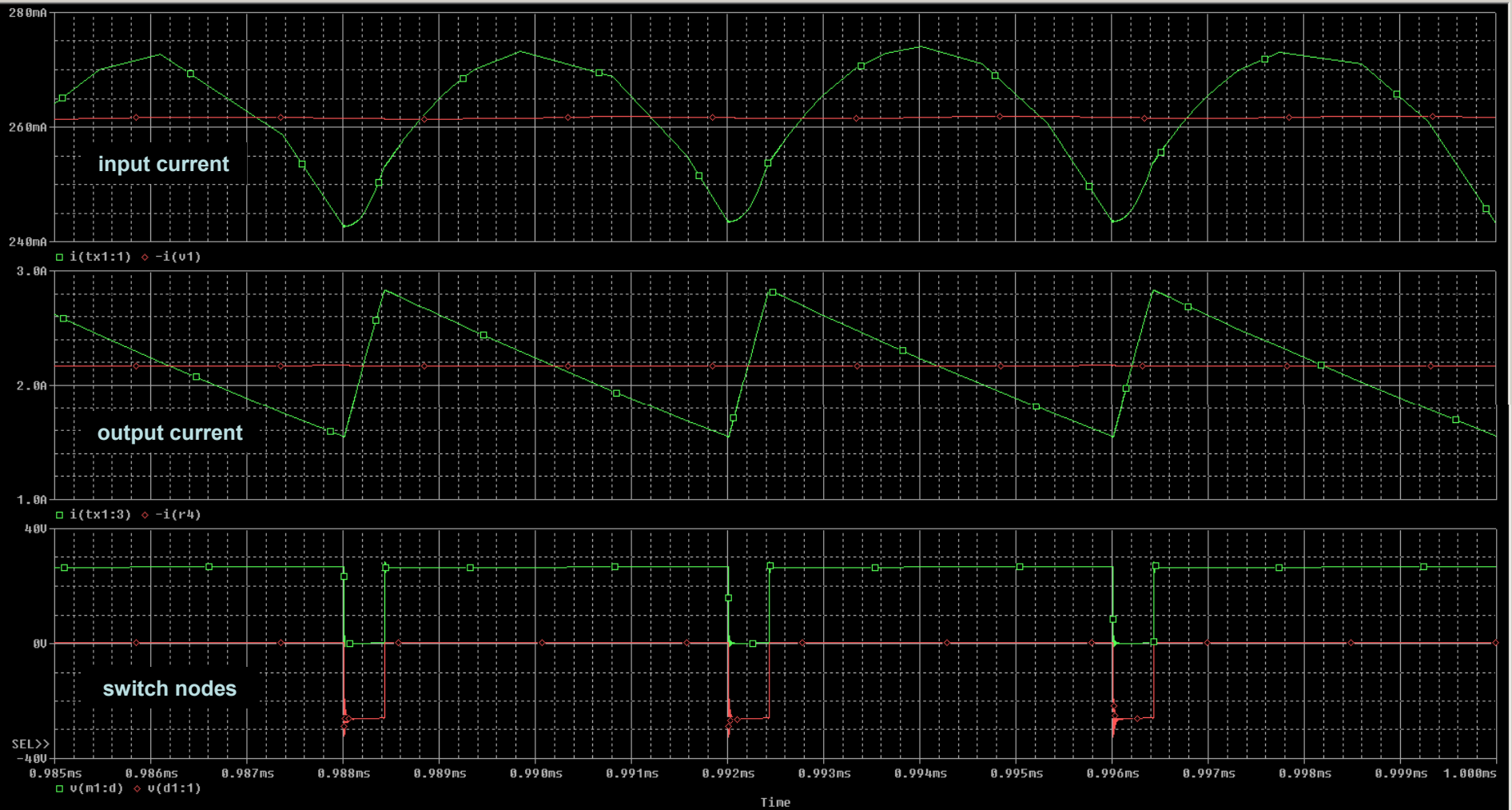


voltage at COMP pin overrides LTC3704 internal error amplifier and sets trip current in Q1, at which Q1 is turned off

TEC Controller DC/DC Converter – SPICE Simulation Circuit



Waveforms @ maximum output (2.2A, 2.3V)



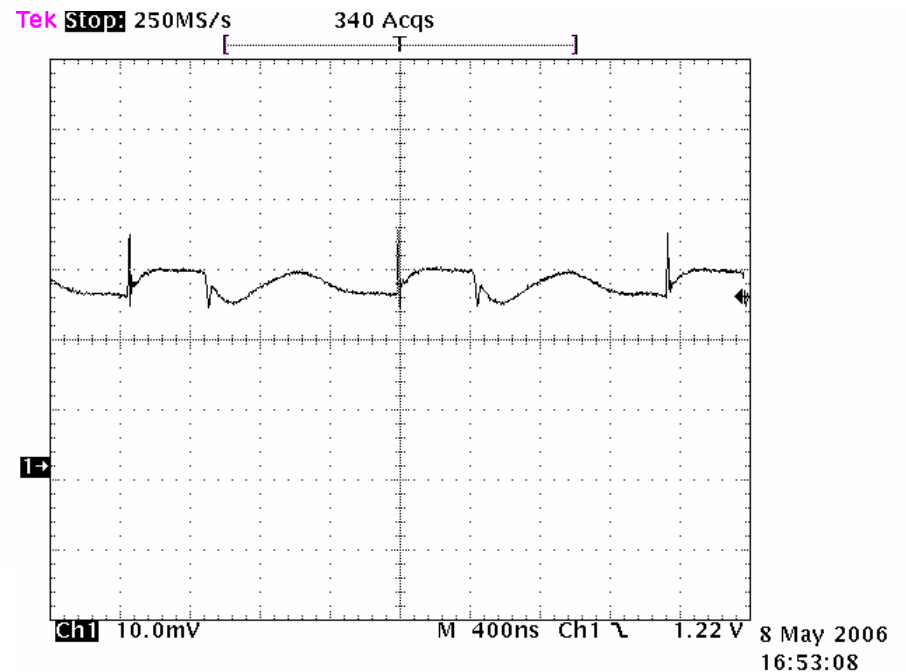
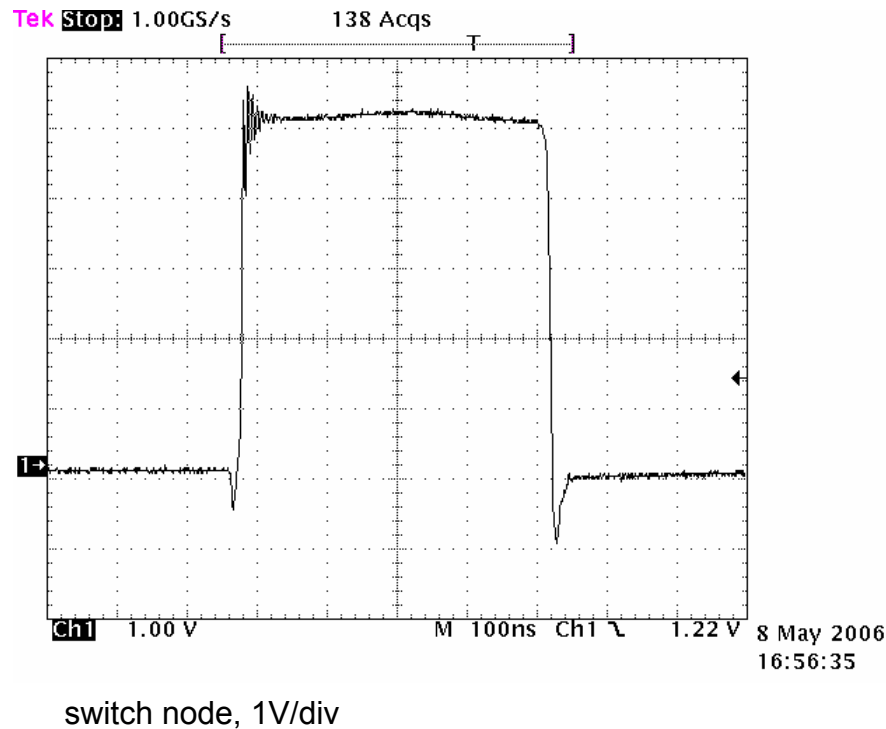
Waveforms @ maximum output (2.2A, 2.3V)



An Example of Good, Clean Switching Converter Waveforms

5V to 1.2V synchronous rectifier buck converter, with 5.8A (6.9W) load,
modified version of EL7566 evaluation board

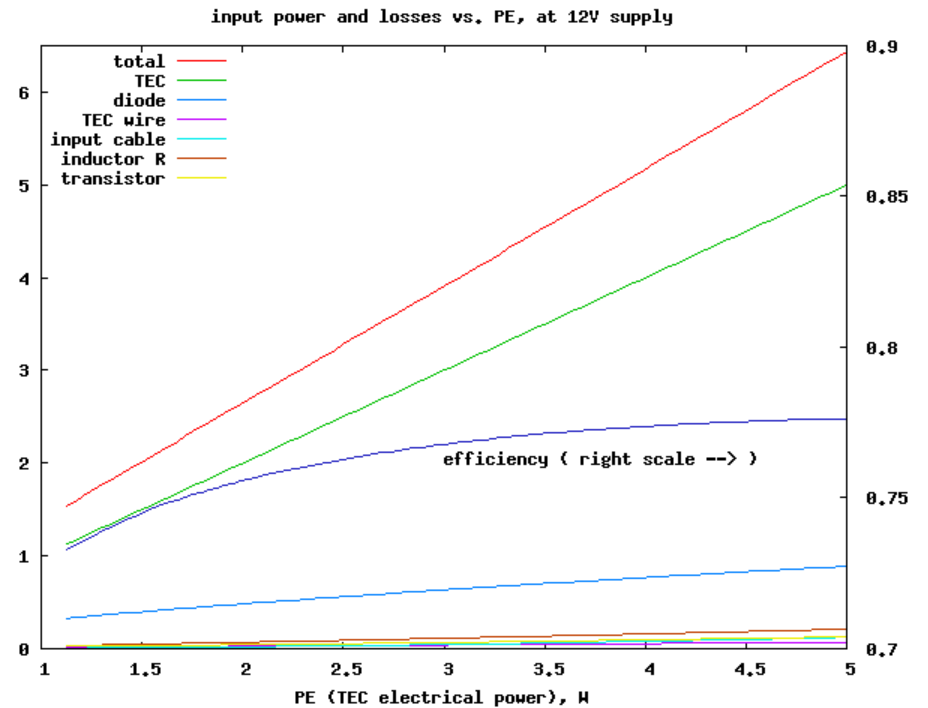
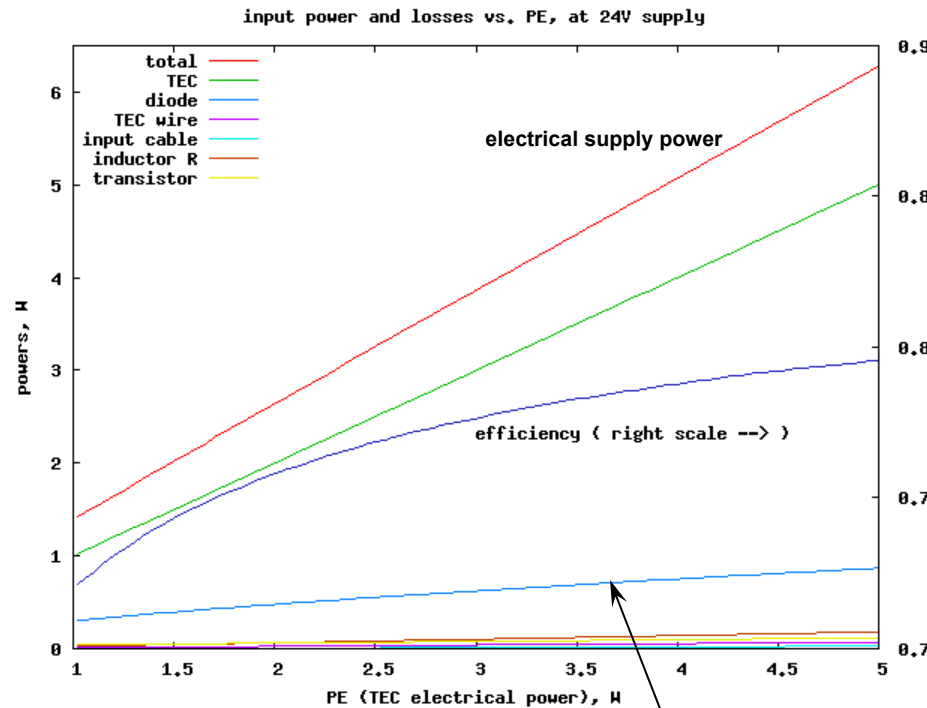
very careful attention to PCB layout and component parasitics is required to achieve this – but it can be done!



output voltage, 10 mV/div

note this is raw output, no additional filter stage
we will use a filter (as shown in schematics above)

TEC Controller DC/DC Converter – Efficiency



CAVEAT – this is not quite a correct calculation – some parts will need a higher current rating for 12V operation, decreasing efficiency a little more, probably about 75%

dominant loss is due to forward voltage of the diode

→ “fundamental” efficiency limit

$$V_{\text{TEC}} / (0.5V + V_{\text{TEC}}) = 82\% \text{ at } 2.3V$$

(or 92% at 6V)

Information Needed to Proceed Further... [As Resolved at Meeting 5/9/2006]

Requirements

- TEC electrical power 3W or 5W or ...? [5W]
- Fixed setpoint or programmable? [programmable, voltage from FEB DAC]
- Temperature readout no or yes? [yes, voltage to FEB ADC (also 2nd ch for drive level)]
- Absolute temperature accuracy? [± 2 °C – BUT note that about ± 1.5 °C of this is just due to component tolerance that can be calibrated out, only about ± 1 °C owing to temperature & other effects in control circuit]

FEB Interfaces

- PCB characteristics: layer stack, available area for TEC controller, overall floorplan, shielding plans, component height restrictions [“anything reasonable”, John says – I will spec it as needed for the TEC controller, we can negotiate if anything conflicts with other requirements on FEB – expect 4layer s/p/p/s; shielding plan probably “use opposite side of board, and/or, mount w/standoffs close onto a ground plate (shielded box)”]
- Connector choices, for input 24VDC and for TEC [TEC up to me, Nathan will send info on 24Vin connector already selected]
- Analog supply voltage(s) available for temperature & error amplifier, ≈ 20 mA load [+2.5V]
- Housekeeping ADC's and DAC's? [yes, there are other DAC's, e.g., for charge pulser, and ADC's on the FEB, so interface from TEC controller to rest of FEB will be analog voltages; DAC and ADC circuit and FPGA design is Harvard's responsibility; I will spec the voltage interfaces to TEC controller]

NTC thermistor characteristics

<http://www.betatherm.com> (excerpted)

Introduction

The 0603 Surface Mount NTC Thermistors from Betatherm are the ideal choice for general temperature sensing and compensation network applications in circuits that require dependable NTC thermistor characteristics. They are available in a wide variety of standard SMD configurations from the 1206 to the 0402 packages. An extensive range of resistance values and tolerances are offered in all of the standard SMD packages. Standard resistance values from 40 ohms to 500 K ohms are manufactured in the different packages. Details of standard resistance values are given for each of the sizes (1206, 0805, 0603, and 0402) as per detailed in the table below. With resistance tolerances of $\pm 1\%$, $\pm 3\%$ and $\pm 5\%$, these NTC devices are suitable for the most demanding requirements. The operating temperature range for these devices is from -40°C to $+125^{\circ}\text{C}$. They are suitable for both flow and reflow soldering processes.

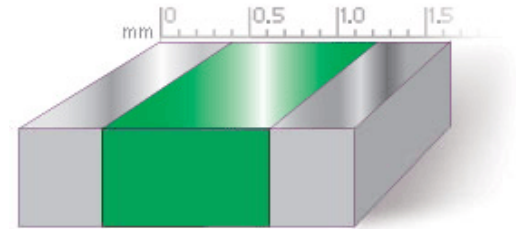
Comparison between NTC thermistors and Metal Element RTD's

Sensitivity: A thermistor offers the best sensitivity of any temperature sensor type in the range from -50°C to $+250^{\circ}\text{C}$. This sensitivity is of the order of -4% to -6% per $^{\circ}\text{C}$. In contrast, Metal Element RTD's have a sensitivity of approximately 0.4% per $^{\circ}\text{C}$. In absolute terms the sensitivity of an NTC thermistor can range from several ohms to several hundred ohms per $^{\circ}\text{C}$, while the sensitivity of a metal element RTD is of the order of 0.4 ohm to 4 ohm per $^{\circ}\text{C}$.

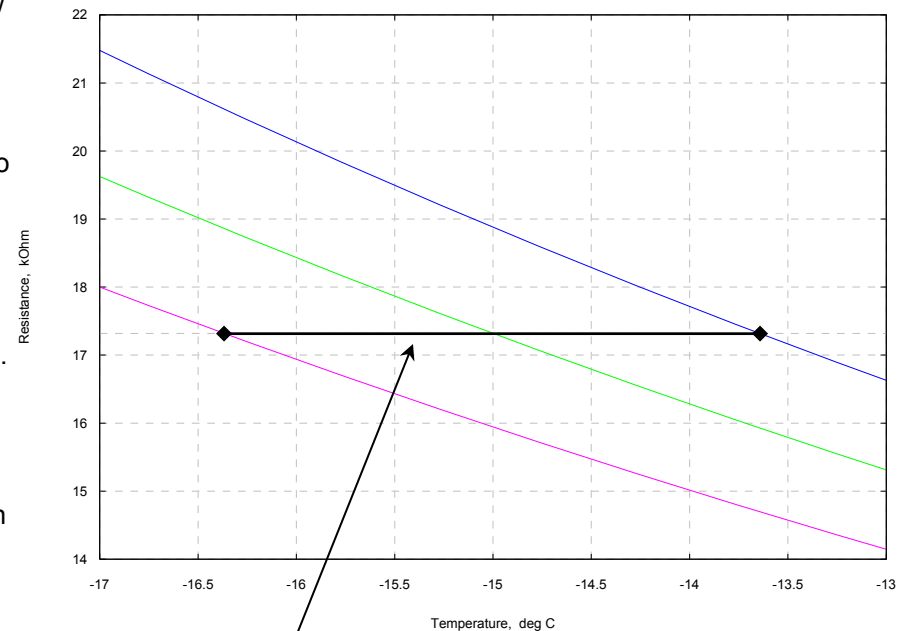
Size: Both an NTC thermistor and Metal RTD can be made to a very small size. In terms of mechanical and electrical performance, NTC thermistors remain durable and robust at small sizes whereas Metal RTD's are more fragile.

Signal Conditioning: The combination of high basic resistance values and high sensitivity of NTC thermistors allows for easy interfacing to instrumentation without significant signal conditioning. Metal element RTD's typically require signal conditioning and amplification and are more susceptible to electrical noise effects.

Temperature Range: The operating temperature range for NTC thermistors is from -100°C to $+300^{\circ}\text{C}$. Metal RTD's offer a wide temperature range from -260°C to $+850^{\circ}\text{C}$.



SMD32KF410H resistance vs. temperature and error band (incl. 1% reference contribution)



Absolute error $\pm 1.4^{\circ}\text{C}$